Multi-profile fine-resolution palynological and micro-charcoal analyses at Esklets, North York Moors, UK, with special reference to the Mesolithic-Neolithic transition

BRUCE ALBERT[1], JAMES INNES[2]

[1] Department of Ecology, Faculty of Environmental Sciences, Czech Life Sciences University, 961/129 Kamýcká, 165 00 Praha-Suchdol, Czech Republic, e-mail: b.m.albert@durham.ac.uk

[2] Geography Department, Durham University, Science Labs, South Road, Durham DH1 3LE, UK

Abstract Multi-proxy palaeoecological data from two peat profiles at Esklets on the North York Moors upland provide a record of vegetation changes for much of the Holocene. Possible vegetation disturbance in the Late Mesolithic and activity in the Neolithic and Bronze Age are recognised. In both profiles fine resolution analyses have been applied to the period leading up to the mid-Holocene Elm Decline which in this upland has been dated to ca. 4,800 BP (uncalibrated ^{14}C years). Disturbance impacts at the Esklets Elm Decline are low scale, but phases of woodland disturbance, which include cereal (*Hordeum*)-type pollen, occur in both profiles ca. 5,200 BP, some centuries before the Elm Decline on the North York Moors, but similar to dates for this key palynological horizon in nearby lowland areas. A protocol is presented for the separation of *Hordeum* (cultivated species) and *Glyceria* (wild grass) pollen. The Esklets sites record disturbances during the Late Mesolithic-Neolithic transition. These pre-Elm Decline disturbance phases represent either early penetration of Neolithic cultivator-pastoralists into this upland or the activities of final Mesolithic foragers. No Neolithic archaeological sites occur nearby, but a 'Terminal Mesolithic' flint site dominated by microlith 'rod' forms occurs close to the palaeoecological sites. Such rod sites are dated in northern England to the centuries leading up to 5,000 BP and so are contemporary with the disturbance phases that included *Hordeum*-type pollen at Esklets. The cultural context of these disturbance phases and the role of 'rod' microlith sites during the Mesolithic-Neolithic transition require further focused research to clarify all issues relating to this important period.

Keywords Mesolithic-Neolithic transition · palynology · Hordeum · woodland disturbance · rod microliths · North York Moors

Introduction

The transition from Mesolithic hunter-gatherer to Neolithic agriculturalist was one of the most significant cultural shifts in prehistory, but in some areas its nature and timing are not clearly defined. This is particularly so in areas peripheral to Early Neolithic settlement in Europe such as the circum North Sea and Baltic regions where hunter-gatherer settlement may have temporally overlapped that of the Neolithic (Innes and Blackford 2009; Wacnik 2009; Deforce et al. 2013; Out and Verhoeven 2014). Debate continues regarding Britain, for example, as to whether the replacement of Mesolithic groups by immigrant Neolithic farmers was swift, or whether a period of cultural and economic substitution occurred. In the latter case, Mesolithic populations might have had time to adapt to changing environmental conditions and encroaching farming settlement, perhaps adopting elements of the incoming Neolithic way of life (Krause-Kyora et al. 2013), until their foraging systems were entirely supplanted. In the Scandinavian and Atlantic margins there is evidence that some of the final Mesolithic groups showed changes in lithic technology (Crombé et al. 2002), as well as general economy (Hartz et al. 2007) that may reflect the influence of contact with approaching Neolithic communities. There are also indications that in some places a degree of co-existence occurred between the two cultures that might have lasted a few centuries (Perrin 2003), with Late Mesolithic groups persisting and perhaps utilising more marginal environmental niches that were not required by the early Neolithic communities. Methods of palaeoenvironmental reconstruction such as palynology may provide botanical evidence for any adoption of agriculture by Late Mesolithic groups in marginal zones, although the reliable separation of cereal pollen from that of wild grasses is problematic and is clearly of critical importance in this respect (Behre 2007; Tinner et al. 2007). A typical example of such uncertainty comes from wetland Mesolithic sites at Schwarzenberg Lake in the South Bohemian uplands, where cereal pollen and high charcoal levels have been found in lake sediments dating to a time when the Early Neolithic Linear Pottery Culture was present in lowland Bohemia. However, pollen grains of possible cereal (cf. *Avena*) type were also found at this Mesolithic site in earlier levels in another core, making cultural interpretation of these pollen records difficult (Pokorný et al. 2009).

In Britain, although the Neolithic is considered (Whittle et al. 2011) to have emerged by ca. 5,200 BP (ca. 6,000 cal BP), archaeological evidence for the earliest Neolithic settlement is sparse. In upland regions, as in the Pennine hills of northern England, it is notable that some radiocarbon dates for the final Mesolithic match those of Early Neolithic sites, suggesting a possible cultural overlap, similar to the European examples mentioned above. The very late Mesolithic dates in upland northern England derive mostly from flint sites where 'rod'-shaped geometric microliths are the only, or heavily dominant, tool form. Importantly, this class of flint site, which is typical of the latter stages of the Mesolithic-Neolithic transition, is assumed to be culturally 'terminal' Mesolithic (Spikins 2002; Chatterton 2007) and may represent a final Mesolithic typological response by indigenous groups to new ecological or social conditions (cf. Crombé et al. 2002). Palaeoecological research may offer supplemental data towards the problem of the Mesolithic-Neolithic transition in Britain, as some of these upland, late variant 'rod' sites of northern England correspond in time to, or are younger than, many dates for the Elm Decline in the adjacent lowlands (Griffiths 2014). Generally occurring a few centuries before 5,000 BP in the lowlands but a few centuries after 5,000 BP in the uplands, this much-debated decline in elm (*Ulmus*) pollen frequencies is often considered to have been the result of the land-use activities of pioneer Neolithic farmers (Edwards 1993), although disease and climate change are other possible contributing factors (Peglar and Birks 1993), so that its origins are possibly multi-causal (Parker et al. 2002). The role of Neolithic pastoralists in the Elm Decline was probably highly significant, however, as the impact of animal browsing on elm can be considerable. In the critical winter season, as well as any elm foliage collected and stored by humans as fodder, highly nutritious young elm wood is favoured by herbivores as other food sources become scarce. Combined faunal and floral ecology studies (Hejcmanová et al. 2014) indicate that elm is an important winter food resource for cattle, which benefit from the high nitrogen and potassium levels in elm twigs and outer branches. Wood pasture has the potential to greatly reduce elm pollen production in spring (cf. Hejcmanová et al. 2014) and so should be visible in pollen diagrams. This is the first in a series of papers in which we examine in detail the ecological events taking place adjacent to Late Mesolithic rod sites in the northern English uplands in the centuries leading up to the Elm Decline, in localities without known Early Neolithic sites, in an attempt to isolate the environmental context specific to rod sites. These investigations aim to assess the character of any impacts on local vegetation by ‘rod site populations’, and also generally improve understanding of the role of people using ‘terminal Mesolithic’ material culture in the Mesolithic-Neolithic transition in Atlantic Europe. Patterns of both cultivation and potential animal husbandry, as indicated by pollen, micro-charcoal and non-pollen palynomorph (NPP) fungal data, are of particular importance in understanding human ecology in the northern English uplands during the transition to a farming economy.

The study area and sites

The study area chosen is the North York Moors in northeast Yorkshire, UK (Fig. 1), an upland that has received considerable previous palaeoecological attention (Simmons et al. 1993). This region has a rich distribution of archaeological sites of all postglacial periods, but sites are particularly well documented from the Late Mesolithic and Bronze Age (Spratt 1993). The summit plateaux of the Moors are covered with late Holocene blanket peat deposits that in many places enclose sediment-filled basins and channels. These depressions are early centres of peat formation and contain sediments dating to mid-Holocene times. Many of these older peat deposits have been studied in order to understand human environmental impacts, some (Fig. 1b) with Late Mesolithic fire-ecology as a major focus of study (Innes and Simmons 1988, 2000; Innes et al. 2010). Events leading up to the Elm Decline have been studied in high resolution in an effort to understand land use and ecological changes during the transition to the Neolithic (Simmons and Innes 1996b; Innes et al. 2013). Early Neolithic archaeological material is not common on the Moors plateaux (Spratt 1993); however, the presence of typologically Neolithic artefacts including leaf-shaped arrowheads and axe-heads demonstrates some Neolithic presence, supporting the attribution of events at the Elm Decline to the activities of early cultivator-pastoralists engaged in some form of forest farming (Edwards 1993). That these Early Neolithic artefacts often occur on Late Mesolithic flint sites suggests an element of spatial linkage between the two cultures’ use of this upland, if only through their co-identification of favourable locations. Any chronological relationship is much more difficult to deduce, however, as there are virtually no radiocarbon dates from the high Moors for these archaeological sites (Innes et al. 2012). The possible co-existence of Mesolithic and Neolithic cultures on the North York Moors, perhaps involving the introduction of novel food resources (e.g. cultigens) and the acculturation of local hunter-gatherers, remains conjectural. The presence of pure ‘rod’ microlith sites on the Moors’ summit plateaux, by analogy with the Pennine evidence (Griffiths 2014), suggests that the Mesolithic occupation of the North York Moors continued almost to the end of the sixth millennium BP, when Neolithic agriculturalists were probably already well-established in the surrounding lowlands. Until ^{14}C dates for the upland artefact sites become available, the recognition of latest Mesolithic and initial Neolithic land use on the Moors plateaux must rely on interpretation of the palaeoecological record. A limitation, however, is that the palaeoecological data cannot securely be linked to either culture, as both Late Mesolithic and Early Neolithic impacts on the vegetation of the North York Moors are possible around the time of the Elm Decline. The aim of this paper is to investigate woodland disturbance phases during this critical transitional period, in sediments as close as possible to a ‘terminal Mesolithic’ rod microlith site in a location with no known Early Neolithic presence. The ecological fingerprint of rod sites, and so potentially also their cultural affinities, may then be revealed.

The sites chosen for this multi-profile, fine-resolution study are at Esklets, on Westerdale Moor, where the head of the Westerdale valley forms an embayment in the central North York Moors summit plateau (Fig. 1c). Although this part of the central watershed of the Moors is an area of very shallow blanket peat and has received little palaeoecological attention previously, there are locations around spring heads and in topographic basins where deeper organic sediments have formed. Some of these deeper profiles are exposed in section and contain wood remains, and are analogous to sites in other areas of this upland where major evidence of mid-Holocene woodland disturbance has been recorded (Simmons 1969; Simmons and Innes 1981, 1988a, b; Innes and Simmons 2000; Innes et al. 2010). The area near the Sweet Banks stream at Esklets (Fig. 1d) was chosen because of the presence of a rod flint site (Hayes 1988; Spratt 1993) and the absence of any Early Neolithic archaeological evidence in the area. Sediment cores were collected at four locations at Esklets, of which cores E1, E2 and E4 were subjected to detailed palaeoecological analysis. (Data from E1 and E4 are presented in this paper. Core E1 is from 100 m north of the Esklets rod site where, in a small basin, a peat section cut by the Sweet Banks stream was available for sampling (UK grid reference NZ665009; 54º 23' 57" N, 0º 58' 38" W; Fig. 1d). The 1 m-deep section included well humified clayey amorphous peat with pine tree stumps low in the profile but above the base of the organic sediment. Core E1 was recovered using two monolith tins. Core E4 is from 600 m to the southwest of the Esklets rod site (UK grid reference NZ659005; 54º 23' 45" N, 0º 59' 9" W) where highly degraded *Betula* tree stumps were exposed at the peat surface. Truncated by erosion, this 35 cm-long core, which was sampled using a Russian corer, contained charcoal bands and mineral inwash layers in the lower part of the core.

The sites E1 and E4, both lying at ca. 370 m above sea level, provide a spatial element to the reconstruction of vegetation history around the Esklets rod site, which itself lies at the south edge of a peat-accumulating small basin shown by coring to be about 150 m in diameter (Fig. 1d, shaded area). Present vegetation consists of *Calluna*-dominated heath and rough grassland.

Materials and methods

2 mm thick sub-samples were analysed in both cores at 2 cm intervals to provide coarse resolution diagrams. Further 2 mm thick analyses were then undertaken at finer-resolution sampling intervals in the Mesolithic-Neolithic transition levels: every 2 mm at E1 (contiguous samples), and every 5 mm at E4 (where humification was less favourable). Laboratory preparation followed standard procedures using KOH, HCL, HF (where mineral sediments are present) and acetolysis, with mounting in silicone fluid (Moore et al. 1991). These procedures have been shown to be also satisfactory for the preparation of most NPPs (Clarke 1994). Pollen identifications were made using the key in Moore et al. (1991) and type slides. At least 800 land pollen grains were counted at most levels. As this study relates to mid-Holocene wooded environments a tree pollen sum has been used as an appropriate basis for pollen frequency calculation (Berglund and Ralska-Jasiewiczowa 1986). Although *Alnus* pollen is sometimes extremely common in this type of mid-Holocene upland-basin peat deposit (Innes and Simmons 2000; Innes et al. 2010), this is not the case at this site, and so *Alnus* has been retained within the tree pollen sum. *Corylus avellana* is regarded as

primarily a shrub, usually only temporarily joining the canopy under disturbed conditions in the mid-Holocene mixed oak forest. It has been excluded from the tree sum, so conforming with all previous published pollen diagrams from the North York Moors. It is shown on the pollen diagrams as '*Corylus*-type' a convention that allows for the possibility that it may include some *Myrica gale* pollen. Although the pollen of the two taxa can generally be separated using light microscopy (Punt et al. 2002), Edwards (1981) notes that it is not always possible to do so. Only a few pollen grains with *Myrica* morphology were encountered in the present investigations (in the later parts of the E1 sequence). These are regarded as indicative of *M. gale* which became established as the moor became more acidic. A pollen grain of Onagraceae was encountered at E1 that is identified as *Ludwigia palustris*, which although rare today may have been more widespread in the past, particularly in small ponds in acid peat environments as were present at Esklets. Frequencies for all pollen and spore types, as well as for microscopic charcoal (micro-charcoal) particles which passed through the 180 μm sieve used in laboratory preparation, are expressed on the microfossil diagrams as percentages of the tree pollen sum. As there is a sedimentary hiatus in core E1 (see below), zonation using statistical techniques was considered inappropriate. Instead, zonation is based on major changes in the curves of ecologically significant taxa as detected by careful inspection of the pollen diagrams. Pollen types have been ordered on the diagrams in life-form groups, with the herbs also sub-divided into ecological groupings as far as possible, e.g. ruderals, telmatics, aquatics, although some are not easily categorised and others such as Poaceae contain many taxa with pollen that cannot be separated morphologically below family level and represent a wide range of different habitats. Our use of the term telmatic follows that of Wheeler and Proctor (2000) in describing semi-terrestrial wetland.

Micro-charcoal particles were counted in the pollen slides relative to the standard pollen count (e.g. Robinson 1984), and were separated into size classes 1-25, 26-50, 51-75, 76-125 and 126-180 μm that relate to settling velocity and distance from fire source (Blackford 2000). All Poaceae grains are also measured and assigned to size classes with a view to a statistical distinction between *Hordeum*-type and *Glyceria*-type (Andersen 1979, 1990; see below). Fungal spores and other NPPs were identified using the published illustrations and descriptions of van Geel and his co-workers (e.g. van Geel 1986, 2001; van Geel et al. 2003). Where NPPs cannot be identified to taxon, the ‘Type’ numbering system with the prefix HdV, as is now common practice, is used. Only selected NPPs of major indicator value (Innes and Blackford 2003; Blackford et al. 2006) are shown on the diagrams.

As the peat in both cores was highly humified and had few macrofossils, small peat samples – six and four samples from cores E1 and E4, respectively – were submitted for AMS ^{14}C dating. In addition, two dates were obtained from in situ wood remains and a further date was obtained from pollen extracted from a basal peat sample taken from core E4. Calibration of the radiocarbon ages was carried out using OxCal 4.2 (Bronk Ramsey 2008, 2009) and the IntCal13 calibration curve (Reimer et al. 2013).

Methodology for Hordeum pollen identification

Hordeum-type pollen identification follows the guidelines of both Andersen (1979, 1990) and Beug (2004). We rely on Beug especially for the distinction of taxa based upon sculpturing aspects of pollen exines (size and clustering patterns of the punctae) and on Andersen particularly for the distinction of taxa based upon size characteristics such as pollen and annulus diameter in silicone fluid. Our use of silicone fluid as the mounting medium (unlike glycerol jelly) avoids expansion of pollen grains over time, as demonstrated by comparative studies for various Poaceae pollen taxa by Andersen (1979), Tweddle et al. (2005) and Joly et al. (2007). Accordingly, we take 38 μm pollen diameter as the lower boundary for cereal-type pollen, although many wild grass species exceed this boundary, and confident identification requires a familiarity with the morphology of large pollen grains of non-domesticated Poaceae. To address this, both glycerol- and silicone fluid-prepared type slides of all major cultigen and problematic wild grass species in the Poaceae collection of the Władysław Szafer Institute of Botany, Kraków, Poland were examined with a view to a fine distinction of *Hordeum vulgare* not only from other cereals (in the sense of Tinner et al. 2007), but also from wild grass species that exhibit similar morphologies (cf. Behre 2007).

With respect to the identification of *Hordeum*, most problematic are wild grass species with identical scabrate sculpturing whose mean pollen grain diameter may exceed the lower size boundary (38 μm) as used in this study. However, some wild barley species, as well as problematic scabrate types like *Elymus* (in Britain represented by coastal *E. farctus*) are in most cases significantly larger than the early cultivated varieties of barley (Andersen 1990; Hall et al. 1993; Tweddle et al. 2005). With respect to the present study which relates to an inland region of northern England, pollen of coastal grasses can be excluded. However, two native species of *Glyceria* (*G. maxima* and *G. fluitans*) that inhabit small ponds and bog pools of the kind that would have been present on the North York Moors are potentially problematic for a palynological identification of barley cultivation. As well as careful inspection of *Glyceria* type slides in the Władysław Szafer Institute of Botany, fresh preparations of *Glyceria* and *Hordeum vulgare* pollen were made using silicone fluid, and the outer annular and mean diameters were measured. To this end, *Glyceria maxima* and *G. fluitans* were collected by John Durkin, County Durham recorder for the Botanical Society of the British Isles from Shibdon Pond in the Tyne Valley, northern England. Subsequently, *Hordeum vulgare* winter varieties were collected at the Gene Bank of the Crop Research Institute, Prague, Czech Republic (accession numbers 01 CO 502100 and 01 CO 502101). Measurements were made at ×1000 magnification under light microscopy of more than 200 pollen grains of *Glyceria* species, and 50 pollen grains of a winter variety of *H. vulgare.* In order to assess further the potential presence of large wild (especially *Glyceria*-type) or domesticated grasses, all Poaceae grains encountered during counting of the Esklets pollen slides were measured and placed into size ranges as noted on the pollen diagrams (31-33 µm corresponds to the main size range of *Glyceria maxima*, 34-36 µm to the main size range of *G. fluitans* and an important size range for *Hordeum vulgare*). On the basis of the type material at the Władysław Szafer Institute, *Glyceria maxima* pollen is minimally problematic, because its size is generally less than 38 µm. As Andersen (1979) noted, *G. fluitans* presents greater problems as its pollen is often as large as that of *Hordeum*. The investigations of the modern *Glyceria* pollen collected at Shibdon Pond support this view insofar as the 38 µm size limit was exceeded in only 5% of the *G. maxima* pollen but in 25% in the case of *G. fluitans*.

It proved possible, however, to establish a protocol for separating *G. fluitans* and cultivated barley based upon annulus measurements of the modern type material. The wild grass has a large outer annulus diameter, and as regards mean diameter

G. fluitans exceeds *H. vulgare* by almost 1.5 µm. In fewer than 5% of cases (3/62), 'cereal-sized' (>38 µm diameter) *G. fluitans* had an outer annular diameter ≤8.5 µm. Because the outer annular diameter of *H. vulgare* seldom exceeds this threshold (cf. Andersen 1990), cereal-type pollen with an outer annular diameter ≤8.5 µm were assigned to *H. vulgare*-type, i.e. cultivated barley. This will actually exclude some pollen of barley, but on the other hand it greatly reduces the probability of assigning *Glyceria* pollen to *Hordeum* (cultivated species). Details of critical grains recorded in profiles E1 and E4 are given in Tables 2 and 3.

Results

Stratigraphy

The main stratigraphic features are shown in Fig. 2, and full Troels-Smith (1955) descriptions are shown in the Electronic Supplementary Material files. The sediments at E1 comprised basal sand, overlain by clayey amorphous organic material with detrital plant remains, wood fragments and small herbaceous roots (turfa), although the turfa and wood elements declined up-profile. Between 62.5 and 65 cm small charcoal fragments were common. From 60 to 62.5 cm the amorphous organic sediment contained detrital plant material and turfa, but little clay, although from 60 cm to the surface the organic sediment became clayey again and contained wood pieces in its upper levels. At E4 a clayey mineral soil lay over basal coarse sand, and was overlain by silty amorphous peat. A sand layer, presumably inwashed material, occurred above this peat, and was overlain by black amorphous organic sediment that contained charcoal fragments, particularly in its lower levels where thin charcoal bands occurred. Above 24 cm a well humified turfa peat continued to the eroded surface, where several highly degraded small *Betula* stumps occurred. Although the amorphous organic material in both cores is described as Sh (*Substantia humosa*), the detrital macrofossils and palynological data suggest that at least some of it may be Ld (*Limus detritus*) gyttja, formed under semi-aquatic depositional environments.

Radiocarbon dating

The AMS, calibrated and modelled ^{14}C dates for Esklets 1 and 4 are presented in Table 1 and Fig. 2. At E1 the part of the core that has been analysed spans early

Holocene to mid-Bronze Age. Dates on either side of the lithostratigraphic boundary at 62.5 cm are more than a thousand years apart, and so there is clearly a major sedimentary hiatus at that level that encompasses the entire Neolithic period, including the Elm Decline. It is unlikely that peat failed to form during that time. It has presumably been removed, perhaps due to intensive local Bronze Age activity. The age-depth curve, which relates to 62.5 cm downwards and includes the entire late Mesolithic period, shows that peat accumulation occurred at a relatively steady rate. At E4, all the post-Neolithic sediment has been eroded, but most of the late Mesolithic and more or less the entire Neolithic is represented. Peat formation began slowly, accelerated at the end of the Mesolithic and seems to have remained at a steady rate throughout the Neolithic.

Palynology

The results of the palynological analyses at sites E1 and E4 are shown in Figs. 3-5. In Fig. 3, the overview E1 profile is presented (pollen spectra at 1 cm intervals). In Fig. 4, the fine-resolution analyses for profile E1 (2 mm thick samples) are presented. The pollen profile E4 (sampling at 5 mm intervals) is presented in Fig. 5. Detailed descriptions of the pollen assemblage zones are given in Table 4. A broad correlation of environmental history is shown in Table 5, and diagnostic elements of Late Mesolithic and Neolithic disturbance phases are summarised in Table 6.

Based on the criteria described above, six Poaceae pollen grains were identified as *Hordeum*, and details are given in Table 2. The diameter of the pollen grains and pore size (including the annulus) are based on two measurements made at right angles and the results rounded up to the nearest 0.5 µm. Two spectra (E1, 63.0 cm and E4, 14.0 cm) provide evidence for barley cultivation based on the evaluation of the Poaceae records (Table 3). *Glyceria* is an unlikely source given the size of the Poaceae pollen. Also in these spectra ruderals and weeds of cultivation are well represented; e.g. *P. lanceolata*, Chenopodiaceae-type (cf. *Chenopodium album*) and composites such as *Taraxacum*-type.

Disturbance evidence at Esklets

Phases of disturbance and/or cultivation are identified as follows: zones E1-f and E1-g (Fig. 3), E1f-2, E1-f4 and E1-g1 (Fig. 4), and E4-b, E4-d and E4-f (Fig. 5).

These are regarded as possible land-use phases. Three of these phases are Mesolithic in age and designated as M1 (possible), M2 (possible) and M3, the last corresponding to the later part of the rod microlith period which is a focus of study here. Phases M1 and M2 mark an early presence of key synanthropic pollen types at Esklets.

At site E1, possible land-use indicators in phase M1 (71 cm) include ruderal types like *P. lanceolata* and Chenopodiaceae (first records), dating to 7,781 cal BP (dates cited derive from the relevant age-depth model). Moderate micro-charcoal and *Calluna* pollen representation suggests low-scale burning. This possible human land-use phase is coeval with the development of a shallow pond at site E1, indicated by the initial appearance of *Ludwigia* and increasing, if low, representation of *Typha* pollen, including *T. latifolia*. Possible land use is again indicated in phase M2 (69 cm; Chenopodiaceae and also *Senecio*). Micro-charcoal data suggest very little burning in M2, while *Calluna* pollen levels are stable. Ponding continues into the Late Mesolithic rod microlith period at E1 (*Typha* pollen), and during the latter part of this period (phase M3, 6,027 cal BP) burning increases dramatically, with micro-charcoal in excess of 50% TLP, but with only moderate increases in *Calluna*. During this phase, elm declines temporarily at 63 cm, where a maximum of ruderal pollen types is encountered, including *P. lanceolata*, Chenopodiaceae, *Senecio* and *Taraxacum*-type. High levels of *Taraxacum*-type are also notable given the prevalence of *Taraxacum* in winter arable fields, including winter barley (Kolářová et al. 2014). Attention is also drawn to maximum values of Chenopodiaceae at E1, which may derive from *Chenopodium album*, also an arable weed of cereals. Two pollen grains of *Hordeum*-type were also noted as well as a maximum of large (50+ μm) micro-charcoal particles, which suggests increased importance of localised fires (Blackford 2000). Small increases of *Calluna* may indicate woodland clearance to facilitate cultivation, rather than changes resulting from browsing and grazing by animals. Above 62.8 cm, coprophilous fungi of the *Cercophora*-type appear as burning, now less localised, continues.

At site E4, an initial possible land-use phase (M3) is approximately coeval (5,996 cal BP) with phase M3 in E1. At E4 (30 cm), *Calluna* achieves a sharp peak in the late Mesolithic, and along with records for *Cercophora* and *P. lanceolata*, indicates a possible land use involving wild or domesticated animal grazing and browsing. High values for micro-charcoal suggest major fires in the region. On the other hand, there is little evidence of fire during the *Hordeum* cultivation in the Neolithic period (phase N). Otherwise, the main ruderal taxa of phase N in E4 are rather similar to those of the late Mesolithic at E1, save for an absence of *Taraxacum*-type and *Stellaria* pollen in E4. The latter taxon, typical also for small woodland clearings, is locally present also during the late Mesolithic (zones E4-b/c). As the maximum pre-Elm Decline disturbance zone (E4-b) itself is marked by presence of diatoms, *Zygnema*-type algae (HdV-58) and a substantial representation of *Typha latifolia* and *T. angustifolia*, it is inferred that an attraction to lacustrine resources, even of limited scale, played a role in late Mesolithic settlement. The period after 5,750 cal BP at E4 is then marked by a reduction of ponding indicators, with diatoms no longer recorded for a time, reappearing immediately after the main Neolithic cultivation episode (10 cm). By 5,600 cal BP, a continuous curve for *Typha latifolia* ends, and by 5,500 cal BP (Elm Decline), records for *Typha* terminate. A lacustrine environment, rich in flora and fauna, probably had attractions for late Neolithic peoples as it had for the late Mesolithic population.

Discussion

Palaeogeography

Whereas the hill slopes to the south, north and east of the Esklets sites are steep and covered by shallow peat, the small area of deeper sediment that surrounds profile E1 (shaded on Fig. 1d) contains stratigraphic and microfossil evidence of aquatic environments, and it is probable that the area formed a shallow pond during much of the early and mid Holocene. Water around this springhead seems to have been ponded in a basin behind a rock escarpment just above the 350 m contour to the west, through which the stream cuts and falls steeply into the Esklets embayment. Such a small, perhaps ephemeral, pond could well have been a focus for human activity throughout its existence, before being overwhelmed by the spread of peat in the later Holocene. The lower levels of E4, on the other main spring-head in the area, also contain aquatic pollen, *Pediastrum* algae and diatoms of *Nitzschia* species, and so would also have formed in at least shallow bog pools but perhaps in a more substantial water body. The mineral and charcoal layers near the base of E4 are interpreted as material washed into this pool during a phase of soil erosion soon after ca. 6,800 cal BP, although indications of disturbance preceding this event include only isolated composites (*Taraxacum* and *Senecio* types). The location of the rod site on the edge of the pond at E1 may be linked to people making use of these localised but potentially resource-rich aquatic environments.

Vegetation history

The profile at E1 provides a vegetation record for the early and mid Holocene. The unsampled surface peat may well be recent, which is not uncommon at high altitude on the North York Moors (Atherden 1989; Blackford and Chambers 1999; Chiverrell 2001; Simmons and Cundill 1974). The base of the pollen diagram at E1 is pre-*Corylus* rise and hence probably dates to near the start of the Holocene, when *Betula* was the only significant tree. The date 8,150±50 BP from near the base of the sequence indicates that *Corylus* was slow to colonise this upland (comparative data are lacking as Esklets represents the earliest peat identified from the high summit plateaux of the Moors). Open vegetation existed in the early Holocene, as *Betula* (this curve includes occasional *B. nana*-type pollen) forms only 40% of TLP in the basal sample, and heath and grassland taxa, i.e. *Calluna*, *Erica*-type, *Empetrum* and Poaceae, are prominent, as well as *Pteridium* spores. Perhaps some form of scrub woodland and heathland existed, resembling the open grassy landscapes of the nearby Yorkshire Wolds upland at this time (Bush 1988), rather than the closed birch woodland of the lowland vales and the lower slopes of the North York Moors.

The mid-Holocene vegetation history at Esklets is similar in character and timing to other profiles from the summit plateaux of the Moors, with a *Corylus*-*Pinus*-*Betula* woodland becoming established, gradually diversified by increases in *Quercus* and *Ulmus*, *Alnus* rising at ca. 7,850 cal BP and *Pinus* declining at ca. 6,800 cal BP. The local presence of *Pinus* is shown by the pine stump in the profile, dated to 7,670±80 BP, a similar age to other dated pine stumps at this altitude on the North York Moors (Innes 2008). The mixed deciduous woodland established around Esklets in the mid Holocene is similar to that recorded at several high altitude springhead sites on the Moors (Simmons 1969; Simmons and Innes 1988a, b; Innes et al. 2010). Until the Elm Decline, the mixed deciduous woodland included *Alnus*, as well as *Quercus*, *Ulmus* and *Corylus*. It is possible that *Alnus* representation was locally controlled, especially by hydrological conditions in the pond-basin. After this period, the oak-alder-hazel woodland became more open, with the spread of heathland taxa in later prehistoric and more recent times. *Tilia* values were consistently low, but otherwise the woodland composition at Esklets that formed the setting for late Mesolithic/early Neolithic human activity was closely comparable to that at analogous sites in the North York Moors.

Pre-Elm Decline disturbance

Previous research in this upland has recorded many instances of generally small-scale woodland recession before the Elm Decline that are characterised by a suite of weed and shrub pollen indicators of canopy opening, disturbed ground and regeneration towards woodland, often with microscopic charcoal records that show that fire was responsible for the disturbances (Innes and Simmons 1988, 2000; Simmons et al. 1993). *Corylus*-type and *Melampyrum* are often the pollen taxa most favoured. These disturbances increase in frequency towards the end of the period (Simmons and Innes 1985) and those of unequivocally Late Mesolithic date typically contain very high levels of microscopic charcoal, unlike the Elm Decline itself when the character of disturbance is different (Innes et al. 2013). There is some evidence at Esklets of limited disturbance in unequivocally Late Mesolithic times (Table 6) with ruderal taxa like Chenopodiaceae and *P. lanceolata* recorded, *Calluna* rising and some low frequencies of micro-charcoal. Although less pronounced than many late Mesolithic disturbances in the area, these instances may nevertheless represent some local hunter-gatherer activity. Several disturbance phases date to only a few centuries before the Elm Decline on the North York Moors, however, and so are analogous in age to the late mid-Holocene episode that is registered in the E1 (6,027 cal BP) and E4 (5,996 cal BP) profiles (see the Bayesian modelling results presented as ESM data) and which is a main focus of this paper. The earliest reliable Elm Decline ^{14}C dates from the lowlands adjacent to the North York Moors are 5,468±80 BP at Neasham Fen and 5,305±55 BP at Mordon Carr (Bartley et al. 1976), both in south-east Durham on fertile limestone soils, and so the Esklets disturbance phases at ca. 5,200 BP are similar in age (or perhaps somewhat later) to the regional lowland Elm Decline, but significantly (at the 2σ level) before the Elm Decline on the Moors upland which occurs at ca. 4,800 BP. Other pre-Elm Decline disturbances of similar radiocarbon age on the high moors plateaux are at Bonfield Gill Head at 5,170±80 BP (Simmons and Innes 1988b) and at several profiles at North Gill (Turner et al. 1993), for example North Gill 2 (5,210±75 BP), North Gill 6 (5,220±45 BP) and North Gill 4 (5,315±45 BP). A similar but undated pre-Elm Decline phase at Bluewath Beck Head (Innes et al. 2010) is of comparable age (by interpolation), and interestingly a phase at North Gill 1A, that interpolates to ca. 5,300 BP or a little later (Simmons and Innes 1996b), contains cereal-type pollen, *P. lanceolata* and other ruderal weed taxa and low micro-charcoal percentages. With the exception of micro-charcoal (Table 6, M3), these data are comparable with the late Mesolithic disturbance at Esklets. Here (E1, E4), local micro-charcoal levels (particles ≥51 μm) are higher.

It appears that there is a distinct class of disturbance phase that occurred in the three to five centuries before the Elm Decline on the high altitude summit plateaux of the North York Moors. These disturbances involved little actual reduction in tree and shrub pollen frequencies and variable levels of burning as indicated by micro-charcoal. The Esklets Late Mesolithic (M3) disturbance events at E1 (ca. 6,027 cal BP) and E4 (ca. 5,996 cal BP) may reflect contemporaneous events at a distance of 750 m, although it is important to note that there is evidence (micro-charcoal ≥51 μm) that strongly supports the notion that fires at E1 and E4 are localized within a radius of ca. 100 m (cf. Blackford 2000), and thus represent spatially distinct events. In the case of E1, barley is cultivated, an activity that favoured Chenopodiaceae, which as anemophilous plants have well dispersed pollen, especially compared with pollen of cereals. Failure to record Chenopodiaceae pollen may be of greater significance than failure to record pollen of cereals (as in E4), given that the latter is very poorly dispersed even over short distances (100 m) (Behre and Kučan 1986). In the case of E4, burning leads to a short-lived expansion of heath vegetation, with *Cercophora* (HdV-112) fungal spores indicating dung and therefore grazing animals nearby (within <100 m radius). This compares well with fire events of the Late Mesolithic that favoured browsing and grazing by animals (Innes et al. 2013).

Interestingly, *P. lanceolata* pollen seems well distributed at both sites, while short-term declines of *Ulmus* (perhaps due to winter browsing animals, cf.

Hejcmanová et al. 2014) are also observed (Table 6). In addition to the pastoral indicative value of *P. lanceolata* (Behre 1981), this ruderal is also a common weed in experimental plots of spring emmer wheat, presently being assessed by the Czech Life Sciences University in Prague (Michal Hejcman, pers. comm. 2014). As the regional upland-lowland age dichotomy for the Elm Decline encompasses several centuries it seems reasonable to conclude that these Esklets events and others like them of similar age on the upland Moors represent cultivation and livestock raising and/or encouraged animal browsing by pioneer Neolithic groups before the local Elm Decline, or the same activities but carried out by Late Mesolithic populations that persisted in the area. It is possible that such 'terminal' Mesolithic bands that were living through the later stages of the 'transition' had adopted enough of the Neolithic economic lifestyle and land-use techniques to become an ecological facsimile of Neolithic incomers, but retaining elements of Mesolithic culture (Innes and Blackford 2009). The latter elements would have included a specialised (rod) microlithic technology and their traditional hunting territories, in a form of 'cultural dualism' (Sørensen and Karg 2014), with the rods being employed in composite cutting tools mounted on wood or antler backing for the purposes of both hunting (projectile points) and cultivation (sickles).

The Elm Decline and Neolithic activity

The Elm Decline is missing in profile E1 due to a hiatus. This interpretation is supported by the ^{14}C dates and the disjunctive pollen/charcoal spectra at ca. 62 cm. The hiatus may be due to Bronze Age activity that resulted in erosion of peat that spanned approximately a millennium, and that included the Elm Decline and most of the Neolithic. The Elm Decline is represented at E4, however, and is a low-scale event. Changes in tree and shrub percentages are small but there is pollen of ruderal weeds and an increase in open ground indicators such as *Calluna* and Poaceae. No major woodland clearance is indicated. It seems to involve a spatially restricted use of ground within the woodland that opened the canopy intermittently, allowing some grazing and perhaps an episode of cultivation for a brief period of time. Records for dung fungi *Cercophora*, *Podospora* and *Sporormiella* at this time support this interpretation (van Geel et al. 2003). Low intensity fodder collection, or stock herding with some cultivation, within the woodland seems likely (Bogucki 1988; Simmons and Innes 1996a; Göransson, 1982; Edwards 1993) rather than 'landnam' agriculture (Rowley-Conwy 1981; O'Connell and Molloy 2001; Brown et al. 2005) as occurred on better soils in regional lowlands. The lower sediments at E4 are extremely well humified and compact, and so finding and studying the low scale and short-lived Elm Decline activity required 5 mm fine-resolution sampling. A slight fall in the already low *Ulmus* curve after 250 mm in E4 proved to be the Elm Decline (Fig. 5). While the Elm Decline on the highest North York Moors is everywhere quite a low-scale event, the feature at Esklets is particularly so, and records an ephemeral impact upon the landscape, without significant woodland removal.

Post-Elm Decline disturbance

As well as the high-resolution data on the Mesolithic-Neolithic transition and Elm Decline, the research at these two Esklets sites has yielded information on human activity during later Neolithic times on this moorland plateau. In E4, *Hordeum*-type pollen joins a suite of open ground weed taxa during a significant activity phase (E4-f) which is age modelled to between 5,183 and 5,116 cal BP. Although considerably larger than the Elm Decline disturbance at this site, woodland impact is still low scale and did not involve significant woodland opening. Previous studies of Neolithic activity on the North York Moors suggest that there was little woodland clearance at altitude and little cultivation, although some did occur. Instead, a gradual thinning of the tree cover through pastoralism and woodland management is usually envisaged (Simmons and Cundill 1974; Atherden 1976). Neolithic archaeological material is concentrated on the lower flanks of the moorland, particularly on the limestone areas (Spratt 1993) and is almost absent from the high plateaux. The low-scale agricultural activity recorded at Esklets and elsewhere at higher altitudes therefore fits very well with this mainly lowland distribution of Neolithic pottery, flint and monuments. That there seems to have been acceleration in peat formation under a wetter climate on the high plateaux during the Neolithic (Simmons et al. 1993) may explain the low level of exploitation by Neolithic farmers. The Esklets data therefore support the view of a mostly low-scale Neolithic exploitation of the high moors, with limited impact on the woodland except in a few atypical locations.

Conclusions

The Esklets data record vegetation disturbance at various levels of intensity around a high altitude pond that varied in size and water depth but persisted through most of the Holocene and formed a long-term focus for human activities and land use. Early disturbances of Mesolithic age, if attributable to human activity, are of low impact but add to the corpus of examples of woodland openings on these upland plateaux that may well have been caused by hunter-gatherers as part of their hunting strategies. In the Esklets profiles, early records of *P. lanceolata* and Chenopodiaceae pollen from before the seventh millennium cal BP are not convincingly associated with fire evidence, and so a 'footpath' indicative value, either human or animal, is considered more likely here (Innes et al. 2010; Kuneš et al. 2008).

Regarding the Early Mesolithic archaeology in northeast Yorkshire (Innes et al. 2011), it is important to note that flint sites of this period also occur at the highest altitude on the Moors (Jacobi 1978). These high altitude plateaux have been included in models of both Early and Late Mesolithic land use, and have been postulated as being a 'hyperforest' zone that had a much more open vegetation than the closed woodland of lower altitudes (Simmons 1975), and so was attractive to game and thus also to Mesolithic hunters. The E1 data allow the testing of that hypothesis for the Early Mesolithic for the first time. It seems that open vegetation existed in the Early Holocene, as *Betula* contributes only 40% of TLP in the basal sample, and heath and grassland taxa are prominent, although any fire disturbance seems minimal after Boreal and Early Atlantic afforestation occurs. Evidence for fires and synanthropic pollen and NPP types is more strongly recorded at the start of the sixth millennium cal BP (land-use phase M3), particularly at E4, where burning over a period of about two centuries is indicated. Human agency in fire setting is suggested not only by dating correlation with Late Mesolithic archaeological materials, but also by the continued burning over a time interval limited to that occupation period only. The short duration of high *Calluna* in response to fires at E4 also suggests that pre-Elm Decline fires were focused on small areas in woodland and did not lead to a significant and lasting expansion of heath vegetation.

It is unfortunate that there is no ^{14}C date for the microlithic flint site at Esklets, and so its age cannot be compared directly with the well-dated Esklets palaeoecological data pertaining to the Mesolithic-Neolithic transition. It is regarded as dating to the final stages of the Late Mesolithic, by analogy with the dated examples of this class of site elsewhere in northern England (Switsur and Jacobi 1975; Spikins 1999; Chatterton 2007). Nevertheless, as there appear to be no Early Neolithic archaeological sites in this part of the central moorland plateau, the microlithic flint site at Esklets is the only candidate for a cultural origin for the woodland disturbance phases recorded at ca. 6,000 cal BP. The Esklets rod flint site is assumed to be a very late variant of the Late Mesolithic based on its lithic assemblage typology, thus this last mentioned disturbance phase may well reflect very late Mesolithic activity.

The earliest Neolithic dates from archaeological sites in the North Yorkshire lowlands (Manby et al. 2003) are 5,040±100 BP (5,989-5,583 cal BP) and 5.260±200 BP (6,434-5,600 cal BP) from Whitegrounds near Malton, and 5,030±90 BP (5,931-5,599 cal BP) from East Ayton, both in the Vale of Pickering. These dates partly overlap (at 2σ) with radiocarbon dates for the major pre-Elm Decline disturbance at Esklets (even if the Neolithic dates appear to be somewhat younger). This raises the question of the functionality and cultural context of the Esklets rod site, and also other sites of this type in the wider region. The palaeoecological signal at ca. 6,000 cal BP in the two Esklets cores is similar to typical Late Mesolithic impacts (Simmons 1996; Innes et al. 2013) in that fire was clearly employed to open the woodland and promoted the growth of hazel and heather. However, although models of pioneer Neolithic forest farming remain contentious (Ghilardi and O'Connell 2013), the records of cereal-type pollen suggest small-scale cultivation within woodlands (Göransson 1982; Edwards 1993; Moore 1996), in which case the rod and scraper typology of the flint site may be associated with harvesting rather than hunting implements (Zvelebil 1994). Whether such cultivation was carried out by terminal-Mesolithic people, or by initial-Neolithic people adapting an ancient tool form to new functions, remains unclear. The data from Esklets seem to present a complex ecological and land-use signal. A form of 'cultural dualism' as discussed by Sørensen and Karg (2014) may be represented here. Orthodox cultural labels may not even be suitable for describing the social and economic status of people exploiting the northern English uplands during this transitional phase. The Esklets evidence suggests that much more focused archaeological and palaeoecological research is needed regarding these late variant ‘rod’ flint sites, so that their role in the Mesolithic-Neolithic transition in Britain can be clarified and evaluated.

Acknowledgements We are grateful to Chris Orton of the Design and Imaging Unit, Geography Department, Durham University for preparation of the figures, to Charlotte O’Brien for wood identification, to Natasha Barlow for assistance with computer modelling, to the landowner for access to the site and to the Leverhulme Trust for funding the research under project F/00128/BD. We are also grateful to anonymous referees and the editor whose comments led to improvements in the text.

References

Andersen ST (1979) Identification of wild grass and cereal pollen. Dan Geol Unders, Årbog 1978:69-92

Andersen ST (1990) Pollen spectra from two Early Neolithic lugged jars in the long barrow at Bjørnsholm, Denmark. Dan J Archaeol 9:59-63

Atherden M (1976) The impact of late prehistoric cultures on the vegetation of the North York Moors. Trans Inst Brit Geogr NS 1:284-300

Atherden M (1989) Three pollen diagrams from the eastern North York Moors. Naturalist 114:55-63

Bartley DD, Chambers C, Hart-Jones B (1976) The vegetational history of parts of south and east Durham. New Phytol 77:437-468

Behre K-E (1981) The interpretation of anthropogenic indicators in pollen diagrams. Pollen Spores 23:225-245

Behre K-E (2007) Evidence for Mesolithic agriculture in and around central Europe? Veget Hist Archaeobot 16:203-219

Behre K-E, Kučan D (1986) Die Reflektion archäologisch bekannter Siedlungen in Pollendiagrammen verschiedener Entfernung - Beispiel aus der Siedlungskammer Flögeln, Nordwestdeutschland. In: Behre K-E (ed) Anthropogenic indicators in pollen diagrams. Balkema, Rotterdam, pp 95-114

Berglund BE, Ralska-Jasiewiczowa M (1986) Pollen analysis and pollen diagrams. In: Berglund BE (ed) Handbook of Holocene palaeoecology and palaeohydrology. Wiley, New York, pp 455-484

Beug H-J (2004) Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Pfeil, München

Blackford JJ (2000) Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. Palaeogeogr Palaeoclimatol Palaeoecol 164:33-42

Blackford JJ, Chambers FM (1999) Harold’s Bog, East Bilsdale Moor. In: Bridgland DR, Horton BP, Innes JB (eds) The Quaternary of north-east England field guide. Quaternary Research Association, London, pp 91-98

Blackford JJ, Innes JB, Hatton JJ, Caseldine CJ (2006) Mid-Holocene environmental change at Black Ridge Brook, Dartmoor, SW England: a new appraisal based on fungal spore analysis. Rev Palaeobot Palynol 141:189-201

Bogucki P (1988) Forest, farmers and stockherders, early agriculture and its consequences in north central Europe. Cambridge University Press, Cambridge

Bronk Ramsey C (2008) Depositional models for chronological records. Quat Sci Rev 27:42-60

Bronk Ramsey C (2009) Bayesian analysis of radiocarbon dates. Radiocarbon 51:337-360

Brown AG, Hatton J, O'Brien CE, Selby KA, Stuijts I, Caseldine CJ (2005) Vegetation, landscape and human activity in Midland Ireland: mire and lake records from the Lough Kinale-Derragh Lough area, Central Ireland. Veget Hist Archaeobot 14:81-98

Bush MB (1988) Early Mesolithic disturbance: a force on the landscape. J Archaeol Sci 15:453-462

Chatterton R (2007) South Haw, northern England. An upland Mesolithic site in context. In: Waddington C, Pedersen K (eds) Mesolithic studies in the North Sea basin and beyond. Oxbow Books, Oxford, pp 69-80

Chiverrell R (2001) A proxy record of late Holocene climate change from May Moss, northeast England. J Quat Sci 16:9-29

Clarke C (1994) Differential recovery of fungal and algal palynomorphs versus embryophyte pollen and spores by three processing techniques. In: Davis OK (ed) Aspects of archaeological palynology: methodology and applications. AASP Contributions Series 29, Dallas, pp 53-62

Crombé P, Perdaen Y, Sergant J, Van Roeyen J-P, Van Strydonck M (2002) The Mesolithic-Neolithic transition in the sandy lowlands of Belgium: new evidence. Antiquity 76:699-706

Deforce K, Bastiaens J, Van Neer W, Ervynck A, Lentacker A, Sergant J, Crombé P (2013) Wood charcoal and seeds as indicators for animal husbandry in a wetland site during the late mesolithic-early neolithic transition period (Swifterbant culture, ca. 4600-4000 B.C.) in NW Belgium. Veget Hist Archaeobot 22:51-60

Edwards KJ (1981) The separation of *Corylus* and *Myrica* pollen in modern and fossil samples. Pollen Spores 23:205-218

Edwards KJ (1993) Models of forest farming for north-west Europe. In: Chambers FM (ed) Climate change and human impact on the landscape. Chapman and Hall, London, pp 134-145

Ghilardi B, O'Connell M (2013) Fine-resolution pollen-analytical study of Holocene woodland dynamics and land use in north Sligo, Ireland. Boreas 42:623-649

Göransson H (1982) The utilization of the forests in North-West Europe during Early and Middle Neolithic. PACT 7:207-221

Griffiths S (2014) Points in time: the Mesolithic-Neolithic transition and the chronology of late rod microliths in Britain. Oxford J Archaeol 33:221-243

Hall VA, Pilcher JR, Bowler M (1993) Pre-Elm Decline cereal size pollen: evaluating its recruitment to fossil deposits using modern pollen rain studies. Biol Environ (Proc R Ir Acad) 93B:1-4

Hartz S, Lübke H, Terberger T (2007) From fish and seal to sheep and cattle: new research into the process of neolithisation in northern Germany. In: Whittle A, Cummings V (eds) Going over. The Mesolithic-Neolithic transition in North-West Europe. Proceedings of the British Academy 144, Oxford, pp 287-309

Hayes RH (1988) Some Mesolithic sites on the North York Moors. In: Wilson PR (ed) North-East Yorkshire studies: archaeological papers. Yorkshire Archaeological Society, Leeds, pp 1-27

Hejcmanová P, Stejskalová M, Hejcman M (2014) Forage quality of leaf-fodder from the main broad-leaved woody species and its possible consequences for the Holocene development of forest vegetation in Central Europe. Veget Hist Archaeobot 23:607-613

Innes JB (2008) Tree remains from a buried mid-Holocene palaeoforest in upland north-east Yorkshire. Quat Newsl 115:40-43

Innes JB, Blackford JJ (2003) The ecology of Late Mesolithic woodland disturbances: model testing with fungal spore assemblage data. J Archaeol Sci 30:185-194

Innes J, Blackford J (2009) An evaluation of palaeoecological data as evidence of cultural transition in the final Mesolithic millennium of northern and north-western Europe. In: Crombé P, Van Strydonck M, Sergant J, Boudin M, Bats M (eds) Chronology and evolution within the Mesolithic of north-west Europe. Proceedings of an international meeting, Brussels, May 30th-June 1st 2007. Cambridge Scholars Publishing, Newcastle upon Tyne, pp 573-590

Innes JB, Simmons IG (1988) Disturbance and diversity: floristic changes associated with pre-elm decline woodland recession in north-east Yorkshire. In: Jones M (ed) Archaeology and the flora of the British Isles. Oxford University Committee for Archaeology, Oxford

Innes JB, Simmons IG (2000) Mid-Holocene charcoal stratigraphy, fire history and palaeoecology at North Gill, North York Moors, UK. Palaeogeogr Palaeoclimatol Palaeoecol 164:151-165

Innes JB, Blackford JJ, Simmons IG (2010) Woodland disturbance and possible land-use regimes during the Late Mesolithic in the English uplands: pollen, charcoal and non-pollen palynomorph evidence from Bluewath Beck, North York Moors, UK. Veget Hist Archaeobot 19:439-452

Innes JB, Blackford JJ, Simmons IG (2011) Mesolithic environments at Star Carr, the eastern vale of Pickering and environs: local and regional contexts. J Wetl Archaeol 11:85-108

Innes JB, Laurie T, Simmons IG (2012) The age of the Late Mesolithic on the North York Moors, England: radiocarbon dating of a small flint artefact stratified within peat from East Bilsdale Moor. J Wetl Archaeol 12:48-57

Innes JB, Blackford JJ, Rowley-Conwy PA (2013) Late Mesolithic and early Neolithic forest disturbance: a high resolution palaeoecological test of human impact hypotheses. Quat Sci Rev 77:80-100

Jacobi RM (1978) Northern England in the eighth millennium bc: an essay. In: Mellars P (ed) The early postglacial settlement of northern Europe. Duckworth, London, pp 295-332

Joly C, Barillé L, Barreau M, Mancheron A, Visset L (2007) Grain and annulus diameter as criteria for distinguishing pollen grains or cereals from wild grasses. Rev Palaeobot Palynol 146:221-233

Kolářová M, Tyšer L, Soukup J (2014) Weed vegetation of arable land in the Czech Republic: environmental and management factors determining weed species composition. Biologia 69:443-448

Krause-Kyora B, Makarewicz C, Evin A, Flink LG, Dobney K, Larson G, Hartz S, Schreiber S, Von Carnap-Bornheim C, Von Wurmb-Schwark N, Nebel A (2013) Use of domesticated pigs by Mesolithic hunter-gatherers in northwest Europe. Nature Comm. 4 (2348) DOI: 10.1038/ncomms3348

Kuneš P, Pokorný P, Šída P (2008) Detection of the impact of early Holocene hunter-gatherers on vegetation in the Czech Republic, using multivariate analysis of pollen data. Veget Hist Archaeobot 17:269-287

Manby TC, King A, Vyner B (2003) The Neolithic and Bronze Ages: a time of early agriculture. In: Manby TC, Moorhouse S, Ottaway P (eds) The archaeology of Yorkshire. An assessment at the beginning of the 21st century. Yorkshire Archaeological Society Occasional Paper 3, Leeds, pp 35-116

Moore PD (1996) Hunting ground for farmers. Nature 382:675-676

Moore PD, Webb JA, Collinson ME (1991) Pollen analysis, 2nd edn. Blackwell, Oxford

O’Connell M, Molloy K (2001) Farming and woodland dynamics in Ireland during the Neolithic. Biol Environ (Proc R Ir Acad) 101B:99-128

Out W, Verhoeven K (2014) Late Mesolithic and Early Neolithic human impact at Dutch wetland sites: the case study of Hardinxveld-Giessendam De Bruin. Veget Hist Archaeobot 23:41-56

Parker AG, Goudie AS, Anderson DE, Robinson MA, Bonsall C (2002) A review of the mid-Holocene elm decline in the British Isles. Prog Phys Geog 26:1-45

Peglar SM, Birks HJB (1993) The mid-Holocene *Ulmus* fall at Diss Mere, south-east England - disease and human impact? Veget Hist Archaeobot 2:61-68

Perrin T (2003) Mesolithic and Neolithic cultures co-existing in the upper Rhône valley. Antiquity 77:732-739

Pokorný P, Šída P, Chvojka, O, Žačková, P, Kuneš P, Světlík, I, Veselý, J (2009) Palaeoenviromental research of the Schwarzenberg Lake, southern Bohemia, and exploratory excavations of this key Mesolithic archaeological area. Památky Archeol 101:5-48

Punt W, Marks A, Hoen PP (2002) The Northwest European pollen flora, 66: Myricaceae. Rev Palaeobot Palynol 123:99-105

Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hattz C, Heaton TJ, Hoffmann DL, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Staff RA, Turney CSM, van der Plicht J (2013) IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 Years cal BP. Radiocarbon 55:1,869-1,877

Robinson D (1984) The estimation of the charcoal content of sediments. A comparison of methods on peat sections from the Isle of Arran. Circaea 2:121-128

Rowley-Conwy P (1981) Slash and burn in the temperate European Neolithic. In: Mercer R (ed) Farming practice in British prehistory. Edinburgh University Press, Edinburgh, pp 85-96

Simmons IG (1969) Pollen diagrams from the North York Moors. New Phytol 69:807-827

Simmons IG (1975) Towards an ecology of Mesolithic man in the uplands of Great Britain. J Archaeol Sci 2:1-15

Simmons IG (1996) The environmental impact of later Mesolithic cultures. Edinburgh University Press, Edinburgh

Simmons IG, Cundill PR (1974) Late Quaternary vegetational history of the North York Moors I. Pollen analyses of blanket peats. J Biogeogr 1:159-169

Simmons IG, Innes JB (1981) Tree remains in a North York Moors peat profile. Nature 294:76-78

Simmons IG, Innes JB (1985) Late Mesolithic land-use and its impacts in the English uplands. Biogeogr Monogr 2:7-17

Simmons IG, Innes JB (1988a) Studies in the Late Quaternary vegetational history of the North York Moors. VIII. Correlation of Flandrian II litho- and pollen stratigraphy at North Gill, Glaisdale Moor. J Biogeogr 15:249-272

Simmons IG, Innes JB (1988b) Late Quaternary vegetational history of the North York Moors. X. Investigations on East Bilsdale Moor. J Biogeogr 15:299-324

Simmons IG, Innes JB (1996a) An episode of prehistoric canopy manipulation. J Archaeol Sci 23:337-341

Simmons IG, Innes JB (1996b) The ecology of an episode of prehistoric cereal cultivation on the North York Moors, England. J Archaeol Sci 23:613-618

Simmons IG, Atherden MA, Cloutman EW, Cundill PR, Innes JB, Jones RL (1993) Prehistoric environments. In: Spratt DA (ed) Prehistoric and Roman archaeology of north-east Yorkshire. CBA Research Report 87, London, pp 15-50

Sørensen L, Karg S (2014) The expansion of agrarian societies towards the north - new evidence for agriculture during the Mesolithic/Neolithic transition in Southern Scandinavia. J Archaeol Sci, 51, 98-114.

Spikins PA (1999) Mesolithic northern England: environment, population and settlement. BAR British Series 283. Archaeopress, Oxford

Spikins PA (2002) Prehistoric people of the Pennines. West Yorkshire Archaeological Service, Leeds

Spratt DA (ed) (1993) Prehistoric and roman archaeology of north east Yorkshire. CBA Research Report 87, London

Switsur VR, Jacobi RM (1975) Radiocarbon dates for the Pennine Mesolithic. Nature 256:32-34

Tinner W, Nielsen EH, Lotter AF (2007) Mesolithic agriculture in Switzerland? A critical review of the evidence. Quat Sci Rev 26:1,416-1,431

Troels-Smith J (1955) Characterisation of unconsolidated sediments. Dan Geol Unders, Række IV, 3:1-73

Turner J, Innes JB, Simmons IG (1993) Spatial diversity in the mid-Flandrian vegetation history of North Gill, North Yorkshire. New Phytol 123:599-647

Tweddle JC, Edwards KJ, Fieller NRJ (2005) Multivariate statistical and other approaches for the separation of cereal from wild Poaceae pollen using a large Holocene dataset. Veget Hist Archaeobot 14:15-30

van Geel B (1986) Application of fungal and algal remains and other microfossils in palynological analyses. In: Berglund BE (ed) Handbook of palaeoecology and palynology. Wiley, New York, pp 497-505

van Geel B (2001) Non-pollen palynomorphs. In: Smol JP, Birks HJB, Last WM (eds) Tracking environmental change using lake sediments. Volume 3: terrestrial, algal and siliceous indicators. Kluwer, Dordrecht, pp 99-119

van Geel B, Buurman J, Brinkkemper O, Schelvis J, Aptroot A, Van Reenen G, Hakbijl T (2003) Environmental reconstruction of a Roman period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. J Archaeol Sci 30:873-883

Wacnik A (2009) From foraging to farming in the Great Mazurian Lake District: palynological studies on lake Miłkowskie sediments, northeast Poland. Veget Hist Archaeobot 18:187-203

Wheeler BD, Proctor MCF (2000) Ecological gradients, subdivisions and terminology of north-west European mires. J Ecol 88:187-203

Whittle A, Healy F, Bayliss A (2011) Gathering time: dating the early Neolithic enclosures of southern Britain and Ireland. Oxbow Books, Oxford

Zvelebil M (1994) Plant use in the Mesolithic and its role in the transition to farming. Proc Prehist Soc 60:35-74

Figure legends

Fig. 1 Location maps of the North York Moors, in northeast England, showing the position of Esklets relative to other published sites in this upland that preserve macro and micro-charcoal records of pre-Elm Decline age (see Innes and Simmons 1988). In **d** the locations of the Esklets sites E1 and E4 are shown (triangles), and also the adjacent Late Mesolithic flint site (filled circle). The shaded area in **d** indicates the extent of deeper sediment at E1

Fig. 2 Lithostratigraphy, Bayesian age-depth model, AMS ^{14}C dates and outline sedimentary history at Esklets 1(E1) and Esklets 4 (E4). For each dated depth the calibrated age range (BP) is shown with the modelled age in parentheses. Output from OxCal depositional age models uses OxCal 4.2 (Bronk Ramsey 2009), showing modelled age against depth. Age models use the P_sequence depositional model (Bronk Ramsey 2008) and IntCal13 calibration curve (Reimer et al. 2013). The shaded areas represent the 95% probability range confidence interval. Age model data and lithostratigraphic details are given in the Electronic Supplementary Material file

Fig. 3 Palynology results from Esklets 1, expressed as percentages of the total tree pollen sum. In **a** tree and shrub pollen are shown; in **b** herb pollen, spores, selected NPPs and micro-charcoal. Poaceae and micro-charcoal are separated into size classes. Local pollen assemblage zones and uncalibrated ^{14}C dates are also shown. The position of the hiatus between zones E1-f and E1-g is suggested by a solid zone boundary line

Fig. 4 Fine resolution palynology results through zones E1-f and E1-g from Esklets 1, expressed as percentages of the total tree pollen sum. Local pollen assemblage zones and uncalibrated ^{14}C dates are also shown. The position of the hiatus between zones E1-f and E1-g is suggested by a solid zone boundary. Note the depth scale in millimetres because of the fine sampling at 2 mm intervals

Fig. 5 Palynology results from Esklets 4, expressed as percentages of the total tree pollen sum. In **a** tree and shrub pollen are shown; in **b** herb pollen, spores, selected NPPs and micro-charcoal. Poaceae and micro-charcoal are separated into size classes. Local pollen assemblage zones and uncalibrated ^{14}C dates are also shown

Table 1 Results of AMS ^{14}C dating at Esklets, North York Moors

Table 2 *Hordeum*-type pollen identified at Esklets including sculpturing and size characteristics

Table 3 Summary of results of size measurements of Poaceae (non-cultivated) and *Hordeum*-type pollen in pollen spectra considered to indicate barley cultivation

Table 4 Pollen assemblage zone and sub-zone descriptions of pollen profiles at Esklets. Radiocarbon dates are in calibrated years BP and are the mean of the calibrated 2σ range. Bayesian modelled ages are shown in parentheses (see ESM files). There is a hiatus in core E1 immediately below 62 cm. The age-depth model does not apply above this depth

Table 5 Summary of palaeoecological history at Esklets. Radiocarbon dates are in calibrated years BP and are the mean of the calibrated range. Bayesian modelled ages are shown in brackets. The Bronze Age date at Esklets 1 is above the hiatus and therefore not modelled

Table 6 Selected palynomorph and micro-charcoal counts in Mesolithic (M1-M3) and Neolithic (N) land-use phases in profiles E1 and E4, Esklets. Approximately 800 TLP were counted in each spectrum